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(54) A device to measure the sizes and concentration of solid or liquid particles as they move through a fluid

(57) The sizes and concentrations of solid or liquid particles moving with unknown velocity through a fluid are measured without disturbing the trajectories of these particles by allowing the particles to pass through a sample volume defined by a cylindrical beam of parallel light which is thereafter interrupted by an annual mask which is so dimensioned that only a band of light corresponding to the circumference of the cylinder and having a thickness less than that of the particles passes through to be so focussed on a photodiode.

FIGURE 1: The disdrometer

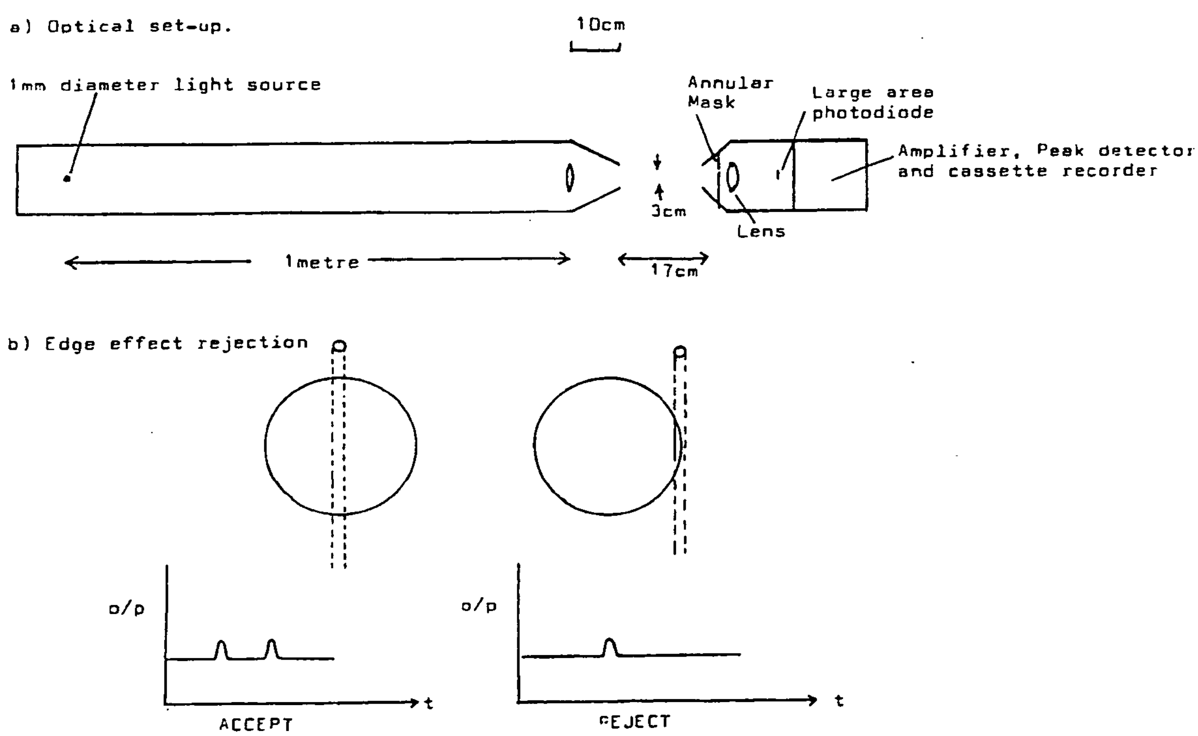

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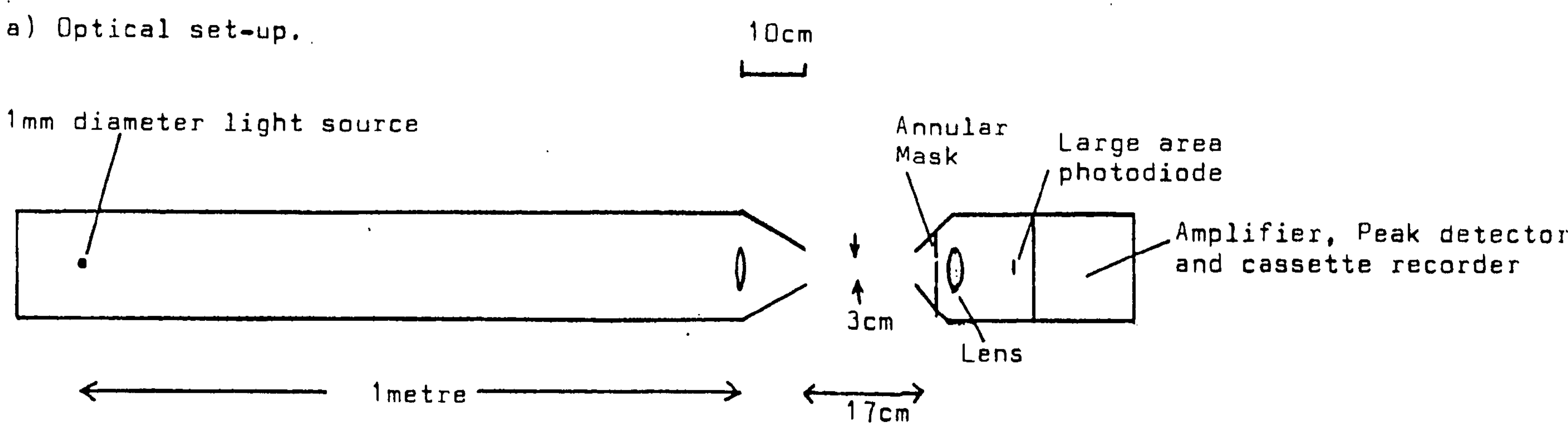
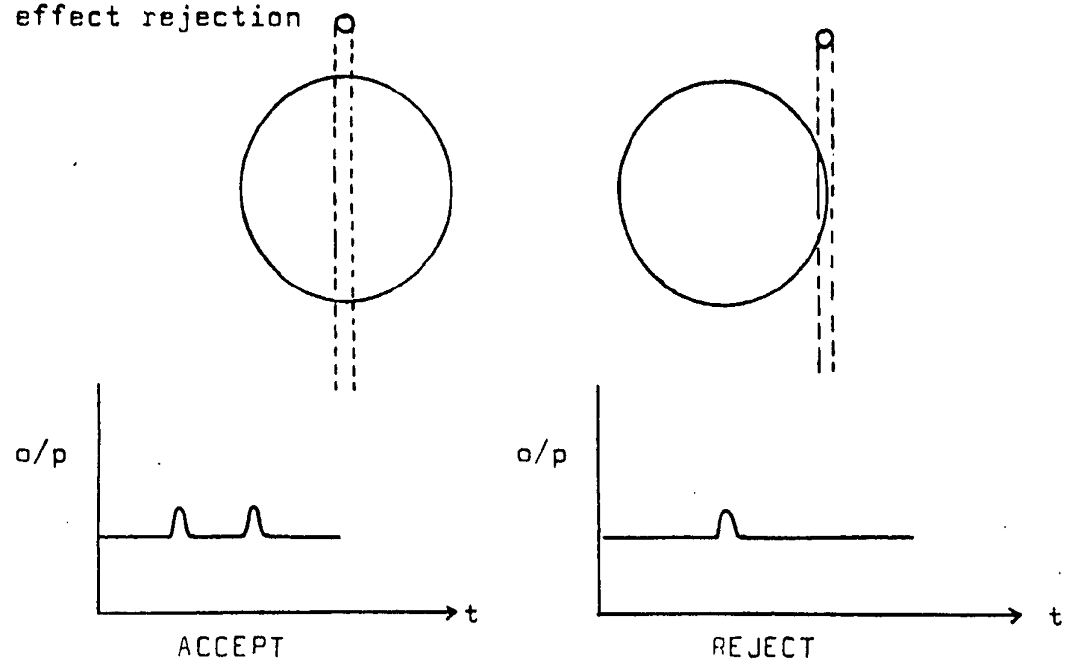
FIGURE 1: The disdrometer

a) Optical set-up.



b) Edge effect rejection



SPECIFICATION

A device to measure raindrop sizes and concentrations

Existing Raindrop Sizing Instruments

Raindrop sizing instruments generally operate on one of two principles. Either the flux of droplets crossing a horizontal surface is measured and the concentration of drops calculated from a knowledge of their velocities, or the number of drops at any instant is measured directly (usually photographically). We shall refer to the two approaches as the "flux" and the "snapshot" methods respectively.

The parameter generally required is the concentration and, where the flux is measured, this must be derived from the drop velocity. In calm conditions this is simply the terminal velocity but, during windy weather, the drop trajectories are liable to be unpredictable, consequently there may be uncertainty as to the projected sample area and the drop velocity. This difficulty should not arise with the "snapshot" method.

Each drop sampled is generally assigned to an appropriate size category and in any distribution the error in the total number for a particular size category may be derived using Poisson statistics. Because the concentration of raindrops generally falls approximately exponentially with size, then for larger drops a larger sample of rain is required to achieve a significant drop count.

Early measurements of raindrop size were derived from the diameter of drop imprints on filter paper, which had been treated with water sensitive dyes, or from replicas in soot or flour. Such methods are very tedious and labour intensive, especially if a continuous record of distributions is required.

Two commercial automatic instruments are available and are described below. They both measure the flux.

A. *Joss-Waldvogel Disdrometer*[1]

This device measures the momentum of drops as they impact upon a 50 cm^2 horizontal plate. Earlier examples of this type had an unacceptable dead time during which the oscillations excited by each impact died away. In this device, however, a complex servo-system keeps the plate stationary. The minimum size detectable is generally 300 μm but this may not be attained during acoustic interference from strong wind or thunderstorms.

B. *The Knollenberg Optical Array Disdrometer*[2]

The PMS ground-based optical array precipitation spectra probe is designed to measure drops over the size range 0.2 to 12.4mm with a sample area up to 60 cm^2. This instrument measures the shadows cast by raindrops on a linear photodiode array.

It has been developed from an aircraft mounted instrument in which case the terminal velocities are negligible compared with the aircraft velocity. On the ground problems will arise with non-vertical drop trajectories during windy weather.

1. Joss J, Thams J C & Waldvogel A 1968 Toronto Cloud Phys Conf, 369-73 "The variation of raindrop size distributions at Locano"
2. Knollenberg R G 1970 J Appl Met, *9* 86-103 "The optical array: an alternative to extinction and scattering for particle size measurements."

The New Raindrop Sizing Instrument

The new device operates on the shadowgraph principle, but, whereas the PMS device has a horizontal rectangular sample area, this instrument detects drops as they enter and leave a cylindrical volume. This cylindrical volume presents an equal area to any drops which, due to high winds, are not falling vertically.

The boundary of the cylindrical sample volume is defined by a narrow sheath of light of uniform intensity and width, formed by allowing a parallel beam of light to be incident upon a mask which only transmits light incident upon a narrow annulus. The light transmitted through the annulus is collected with a lens on to a photodiode; a possible physical realisation of this is discussed in the following Section and in Figure 1. As a drop enters and leaves the cylindrical sample volume it obstructs some of the light incident upon the mask, and providing the sheath is of uniform intensity and thickness, and of a thickness which is much less than the diameter of the drop, then the fall in light collected by the photodiode is proportional to the drop diameter. A drop which enters and leaves the sample cylinder should thus give two equally sized pulses from the photodiode amplifier. A drop which passes through the edge of the sample volume will give a single pulse and this can be rejected (Figure 1). The amplitude of the double pulse pair is a measure of the drop size, and the number of pulse pairs in a given time is a measure of the flux of the drops across the sample volume. To convert this flux into a drop concentration would conventionally require a knowledge of the drop velocity, but this is avoided if the transit time of each drop across the sample volume (that is the time between the entrance pulse and the exit pulse) is measured. If, for a sample time T, the sum of all the individual transit times for a drop of a given size is t, and the sample volume is V, then for a fraction of the time t/T a drop of this size is actually present in the volume V. The concentration of this size of drop is then given directly as t/T drops per volume V.

Possible Physical Realisation

Figure 1 shows the optical arrangement. The device is very simple so that operation in hazardous field environments will be reliable. The use of coherent radiation has been avoided because of interference problems arising from dust particles and the expensive optical elements which would be required. None of the lenses need to be very precisely positioned thus no accurate adjustments are required in the field.

A quarz-halogen filament light source of diameter 1mm at the focus of a lens of focal length 1m provides a parallel beam of light. After this light has crossed the sample volume (in this example a distance of 17cm) it is normally incident upon a mask which only transmits light falling upon an annulus of diameter 3 cm and width 100 μm,thus defining the boundary of the sample volume. The light passing through the annulus is then focused on a large area photodiode. When a drop enters and leaves the volume it should give rise to two equally sized pulses from the photodiode amplifier as it obscures first one side of the annulus and then the other. Provided that the drop is larger than 100μm diameter the amplitude of the pulses should be proportional to the drop diameter. Single pulses resulting from drops passing through the edge of the annulus are rejected in subsequent computer analysis.

Extensions of the Technique

Although discussed in terms of measuring naturally occurring raindrops this technique could be extended to the general measurement of suspensions of drops in fluids of differing refractive indexes moving with unpredictable velocities. The lower limit for the size of drop which can be detected and the upper limit for the sample volume will be set by the departure from geometric shadows due to the diffraction of light. If the sample volume is so large that two or more drops are frequently present within the sample volume then care will be required in identifying the correct exit and entrance pulses.

CLAIMS

I. A method for determining the sizes and concentrations of solid or liquid particles moving through a fluid without disturbing that movement, by measuring, as the particles enter and leave a defined sample volume, the size of the particles using a shadowgraph technique, and the transit time through the sample volume. If for a sample volume V and a total sample time T, particles of a given size are found within the volume for a time t, then the concentration of particles of this size is given by t/(TV).

II. That one way of detecting the droplets as they enter and leave the sample volume is to define the boundaries of a cylindrical volume with a narrow sheath of light of uniform intensity and thickness formed by allowing a parallel beam of light to be incident upon a mask which only accepts light incident upon a narrow annulus. If the particles are larger than the annulus thickness then the diminution in light level collected by the annulus will be linearly proportional to the particle size.

III That such a method is particularly suitable for measuring the sizes and concentrations of raindrops.

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